US009427307B2

(12) United States Patent
Pearson et al.

(10) **Patent No.: US 9,427,307 B2**
(45) **Date of Patent: Aug. 30, 2016**

(54) **CIRCUMFERENTIALLY CONSTRAINING SUTURES FOR A STENT-GRAFT**

(71) Applicant: **Medtronic Vascular, Inc.**, Santa Rosa, CA (US)

(72) Inventors: **Meghan Pearson**, Santa Rosa, CA (US); **Emilie Simmons**, Cotati, CA (US); **Stephen Pearce**, Santa Rosa, CA (US); **Stephannie Rundle**, Santa Rosa, CA (US); **Ana Zavala**, Santa Rosa, CA (US)

(73) Assignee: **Medtronic Vascular, Inc.**, Santa Rosa, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/603,684**

(22) Filed: **Jan. 23, 2015**

(65) **Prior Publication Data**

US 2015/0157445 A1 Jun. 11, 2015

Related U.S. Application Data

(62) Division of application No. 13/458,076, filed on Apr. 27, 2012, now Pat. No. 8,968,384.

(51) **Int. Cl.**

A61F 2/07 (2013.01)
A61F 2/954 (2013.01)
A61F 2/06 (2013.01)
A61F 2/95 (2013.01)

(52) **U.S. Cl.**

CPC ***A61F 2/07*** (2013.01); ***A61F 2/954*** (2013.01); *A61F 2002/067* (2013.01); *A61F 2002/075* (2013.01); *A61F 2002/9511* (2013.01); *A61F 2002/9517* (2013.01); *Y10T 29/49863* (2015.01)

(58) **Field of Classification Search**

CPC A61F 2/07; A61F 2220/0075; A61F 2/82; A61F 2/97; A61F 2/962
USPC 623/1.35
See application file for complete search history.

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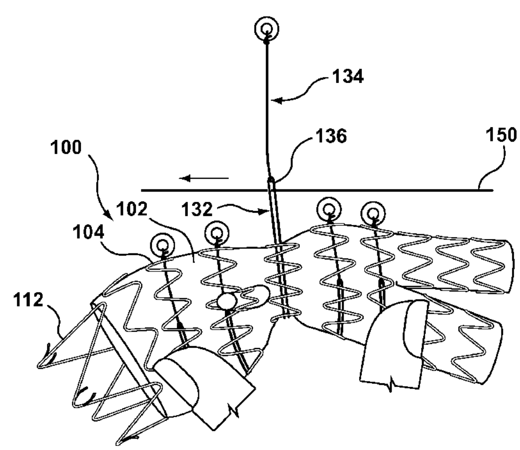
Primary Examiner — Christian Sevilla
Assistant Examiner — Seema Mathew

(57) **ABSTRACT**

A circumferentially constraining suture for an endovascular prosthesis having a tubular body and a plurality of stents coupled to the tubular body includes a first thread coupled at a first end to one of the stents and a first thread loop disposed opposite the first end. The first thread extends only partially around a circumference of the tubular body in a radially expanded configuration. A second thread having a second thread loop is interlocked with the first thread loop and extends from the first thread loop around a remainder of the circumference of the tubular body. Pulling the second thread causes the first thread to circumferentially constrain the tubular body to a reduced diameter configuration. A trigger wire inserted through the first thread loop retains the first thread such that the tubular body is in the reduced diameter configuration after removal of the second thread.

20 Claims, 12 Drawing Sheets



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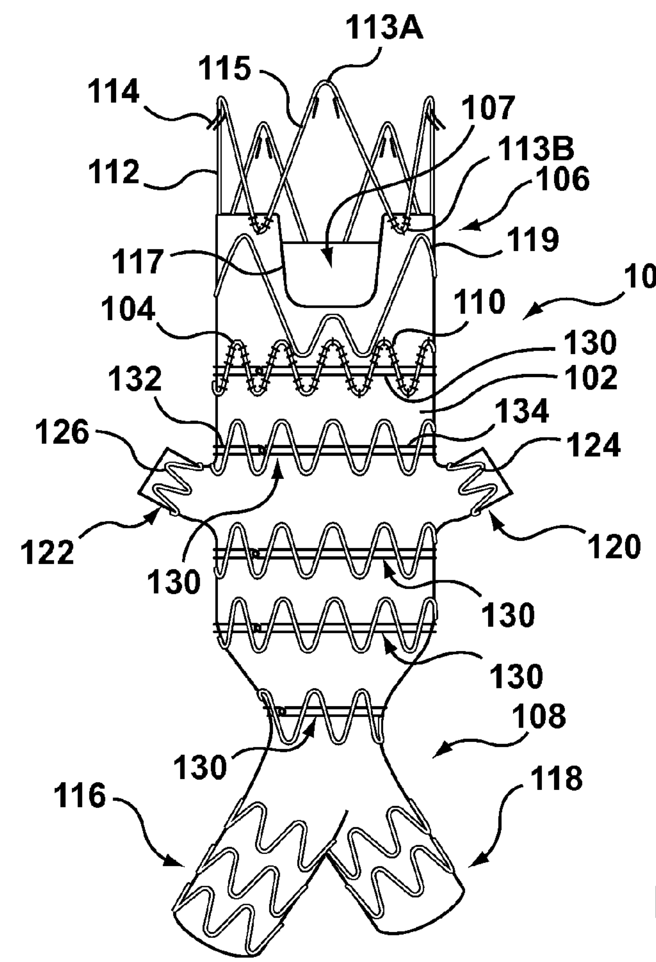

FIG. 1

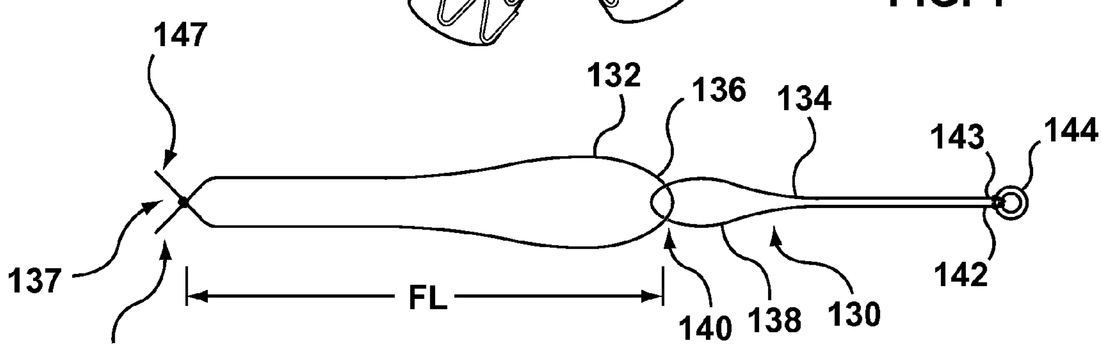

FIG. 2

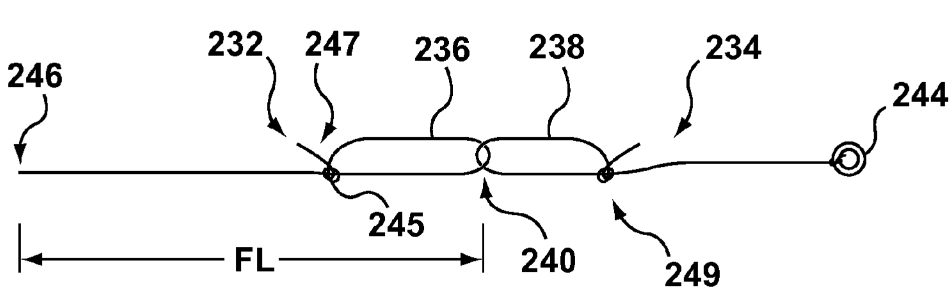

FIG. 2A

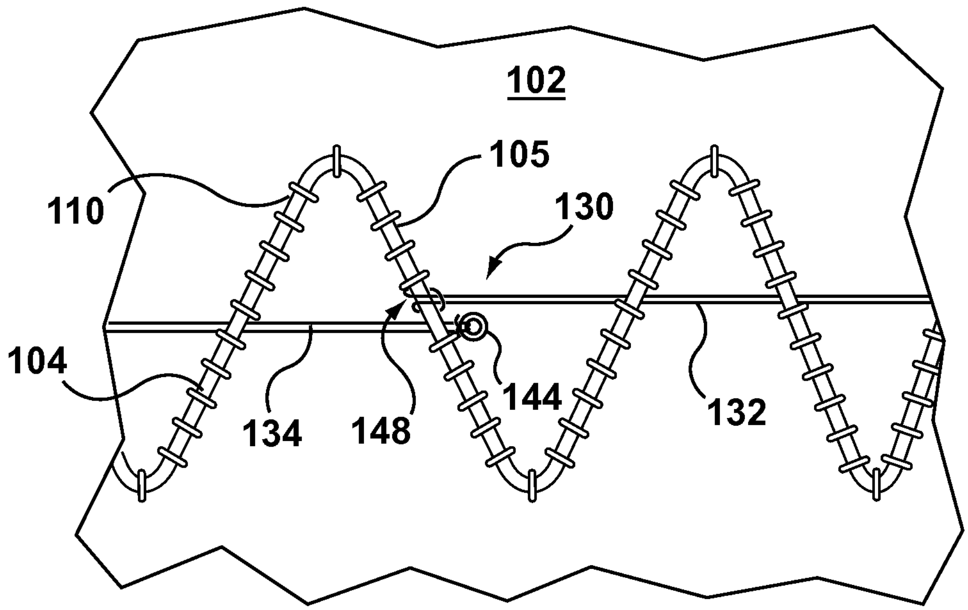
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FIG. 3

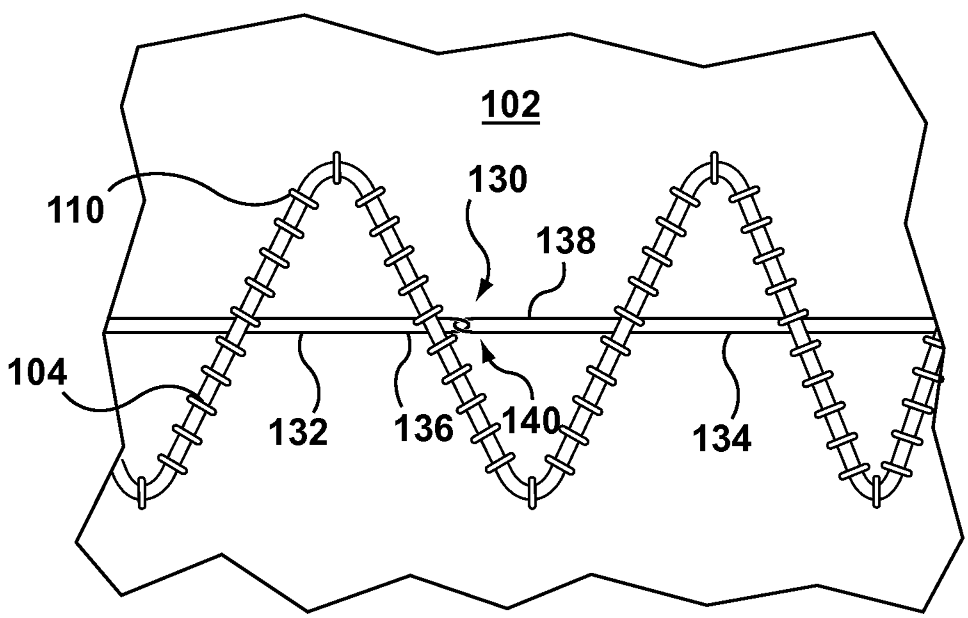
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FIG. 4

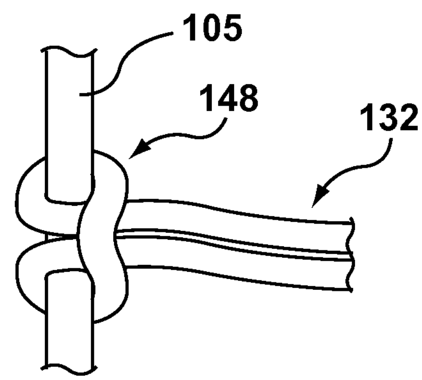

FIG. 3A

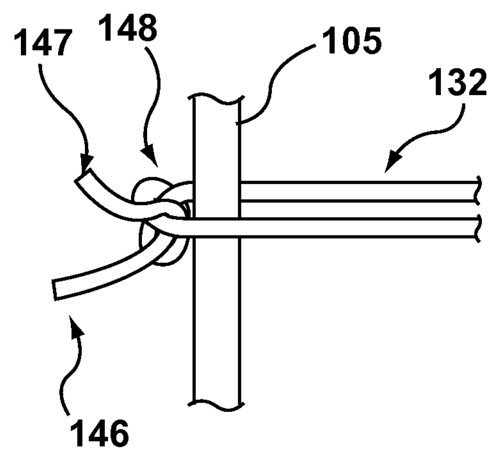

FIG. 3B

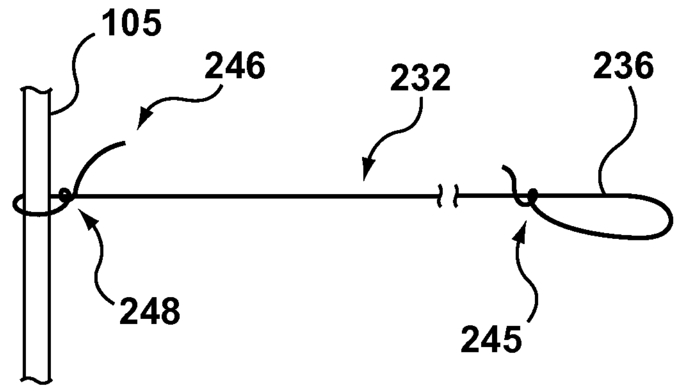

FIG. 3C

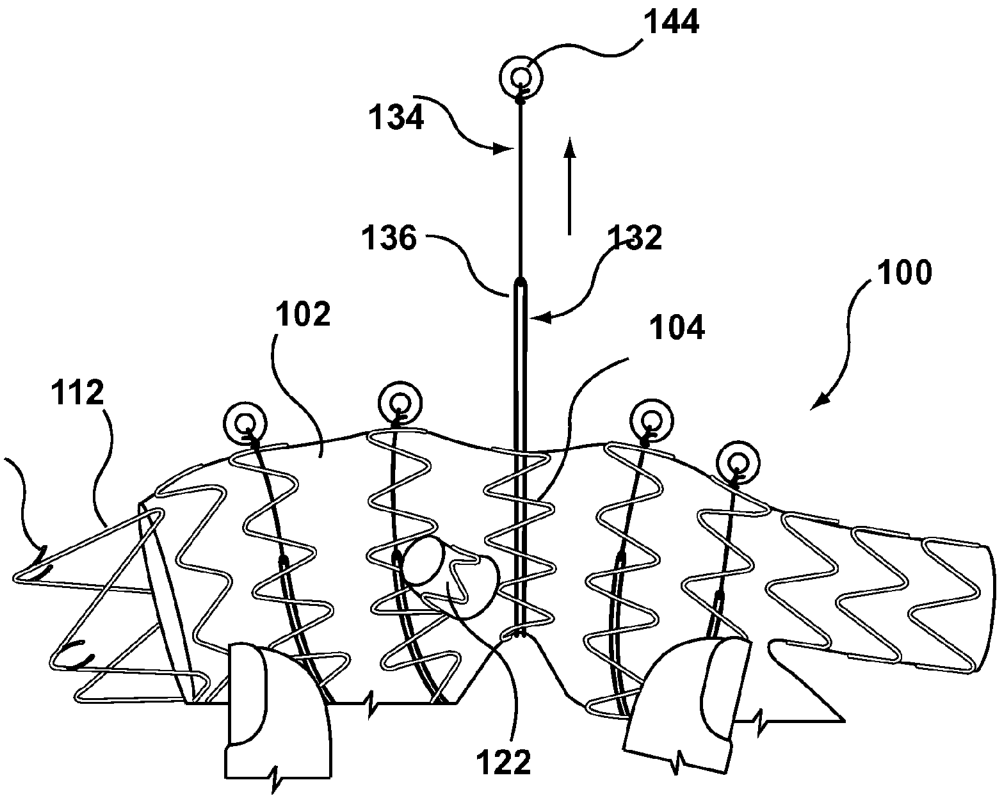
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FIG. 5

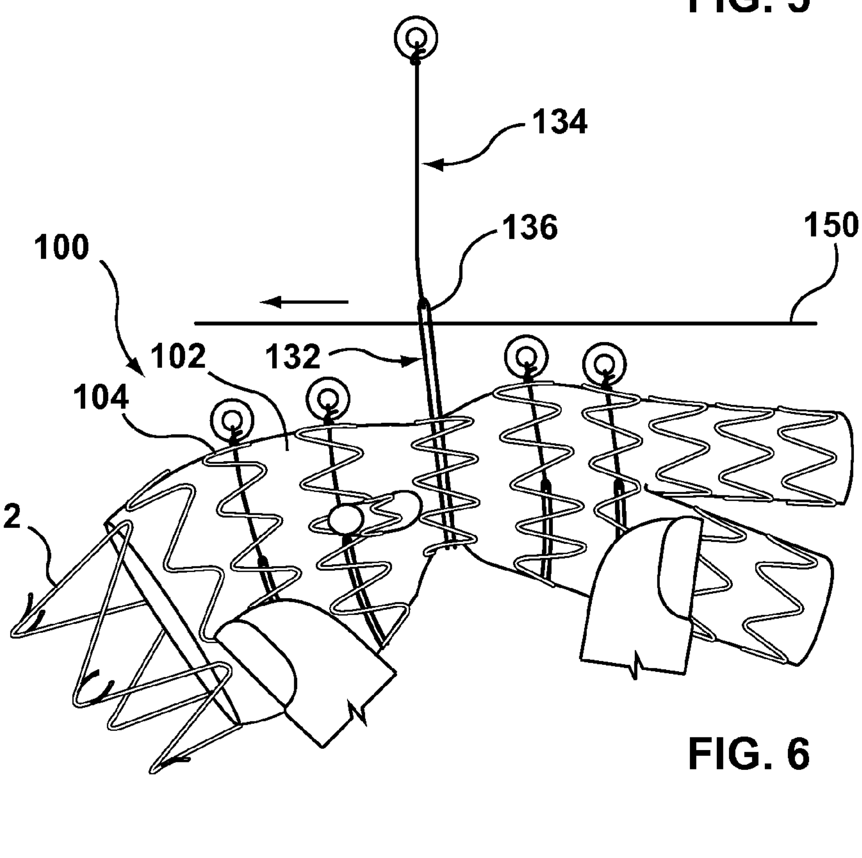
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FIG. 6

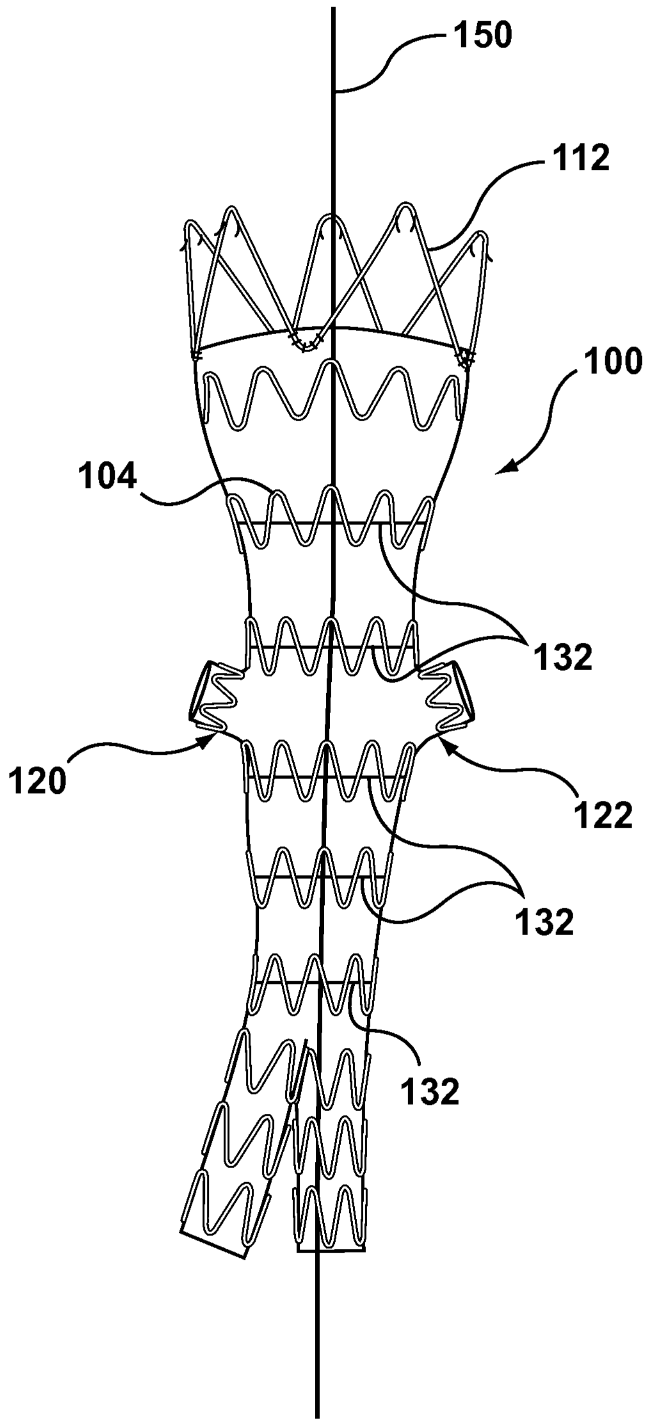


FIG. 7

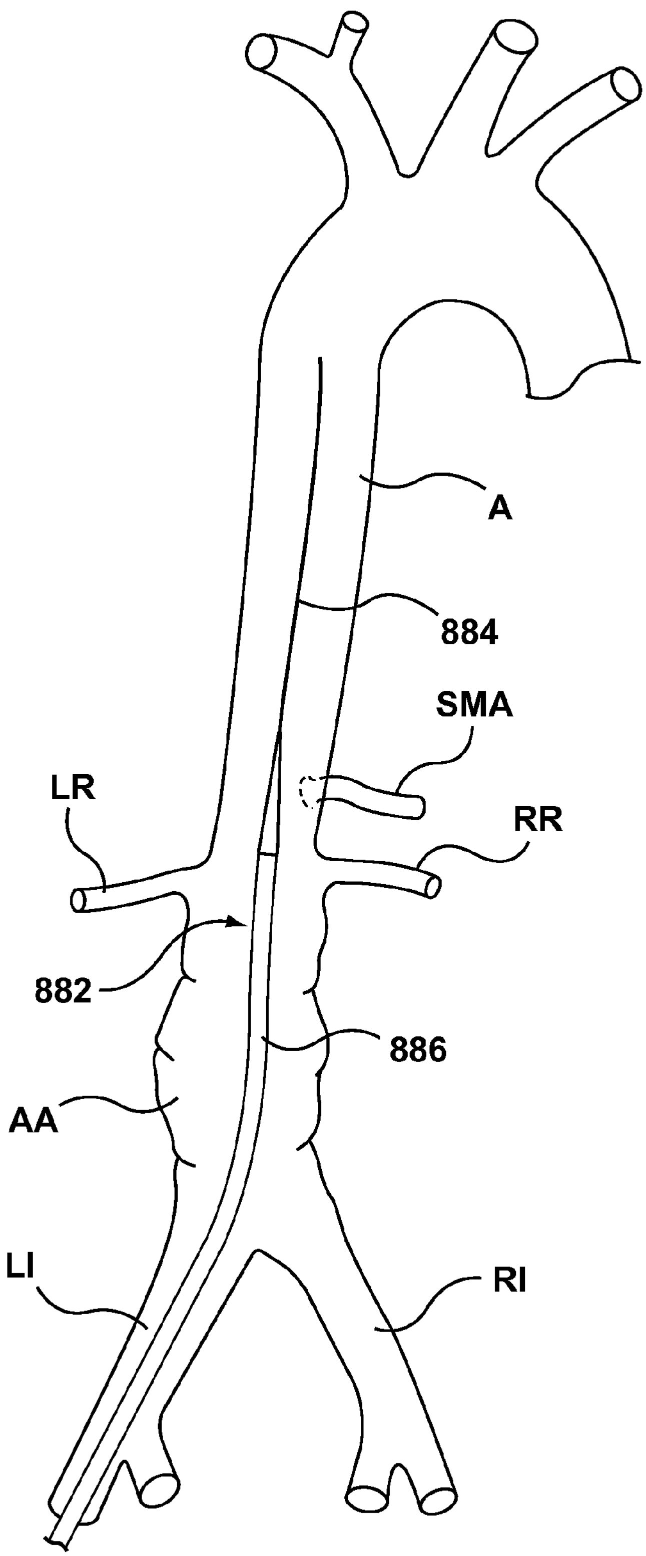


FIG. 8

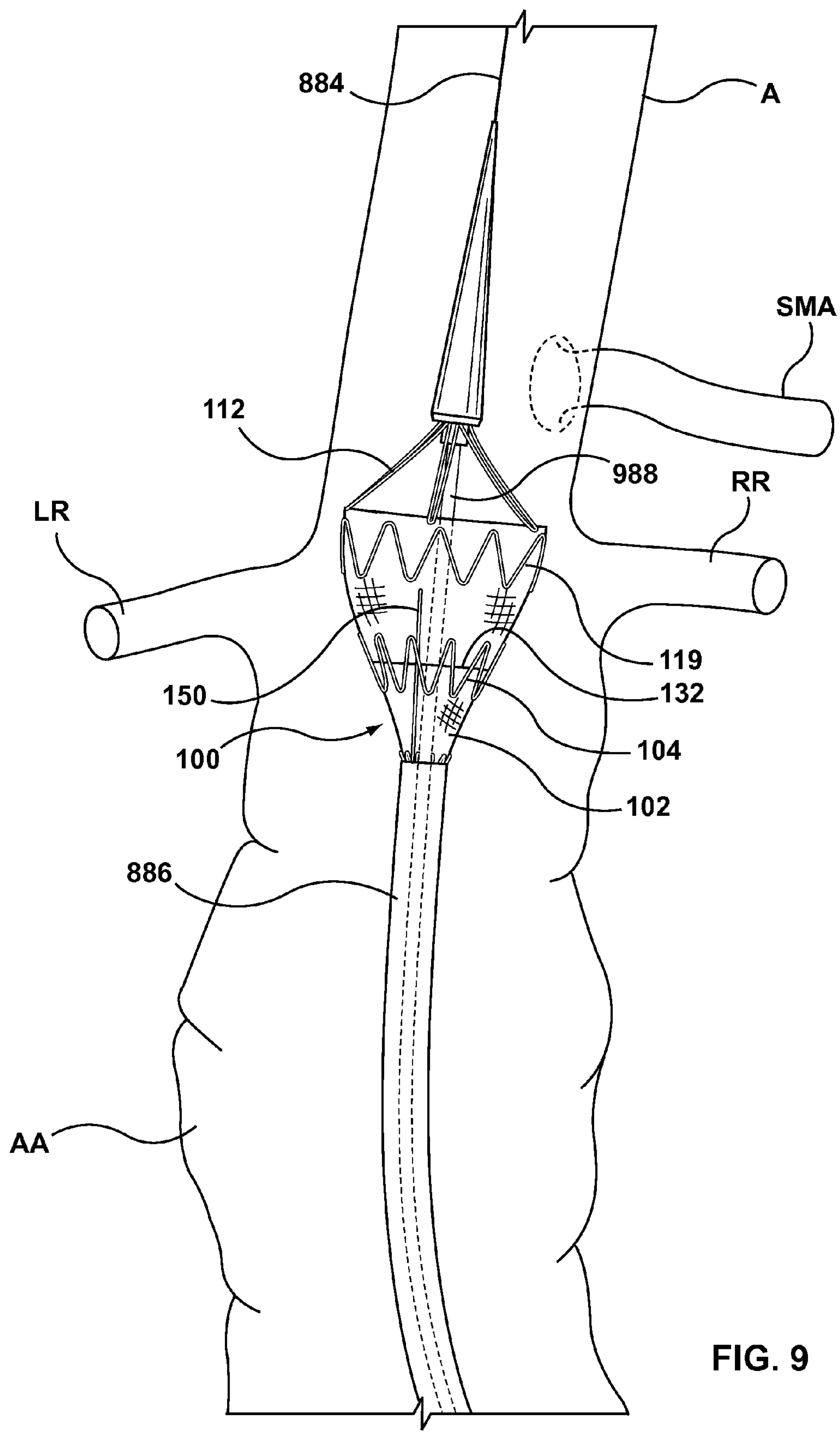


FIG. 9

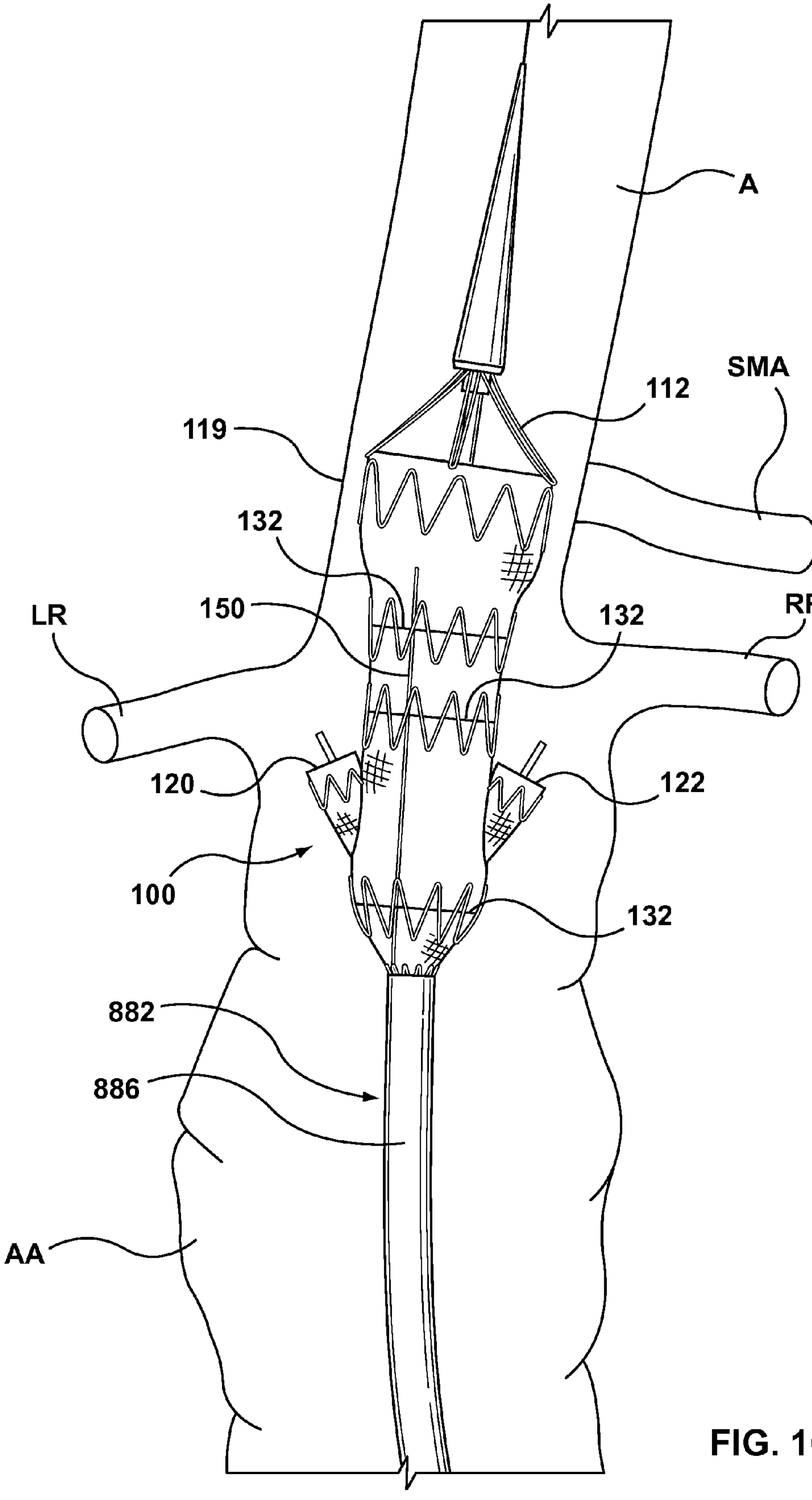


FIG. 10

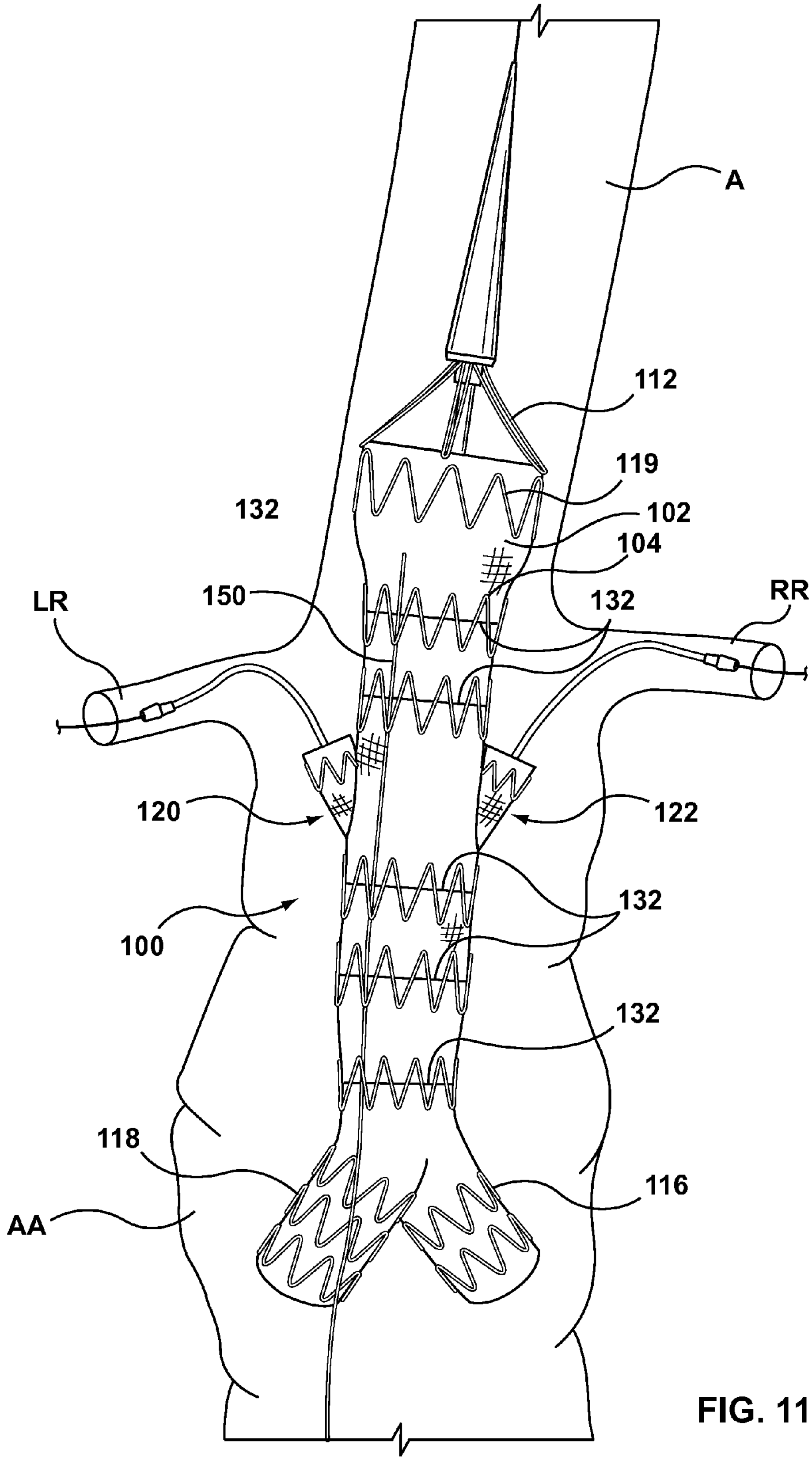
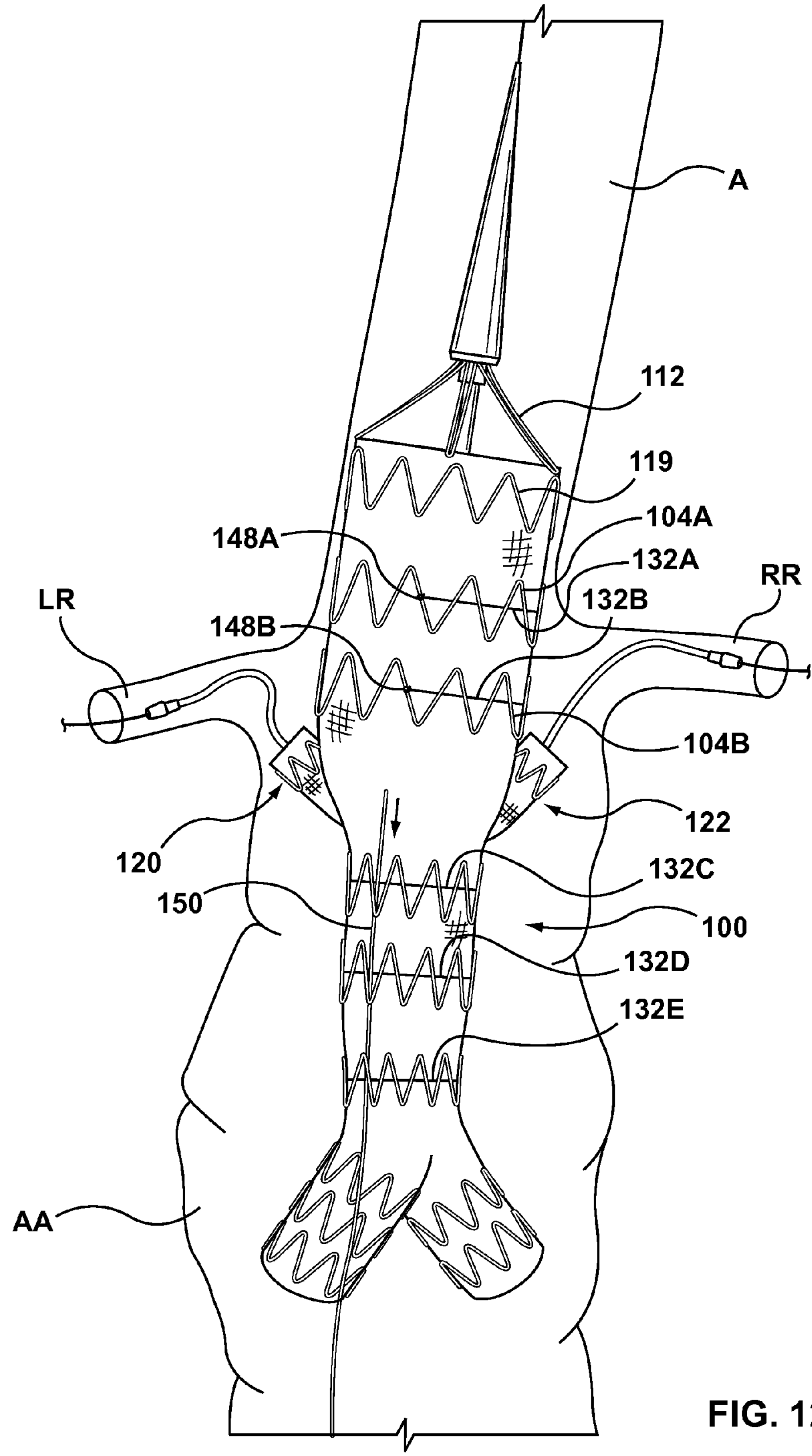


FIG. 11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132C
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100
132D
132E
AA

FIG. 12

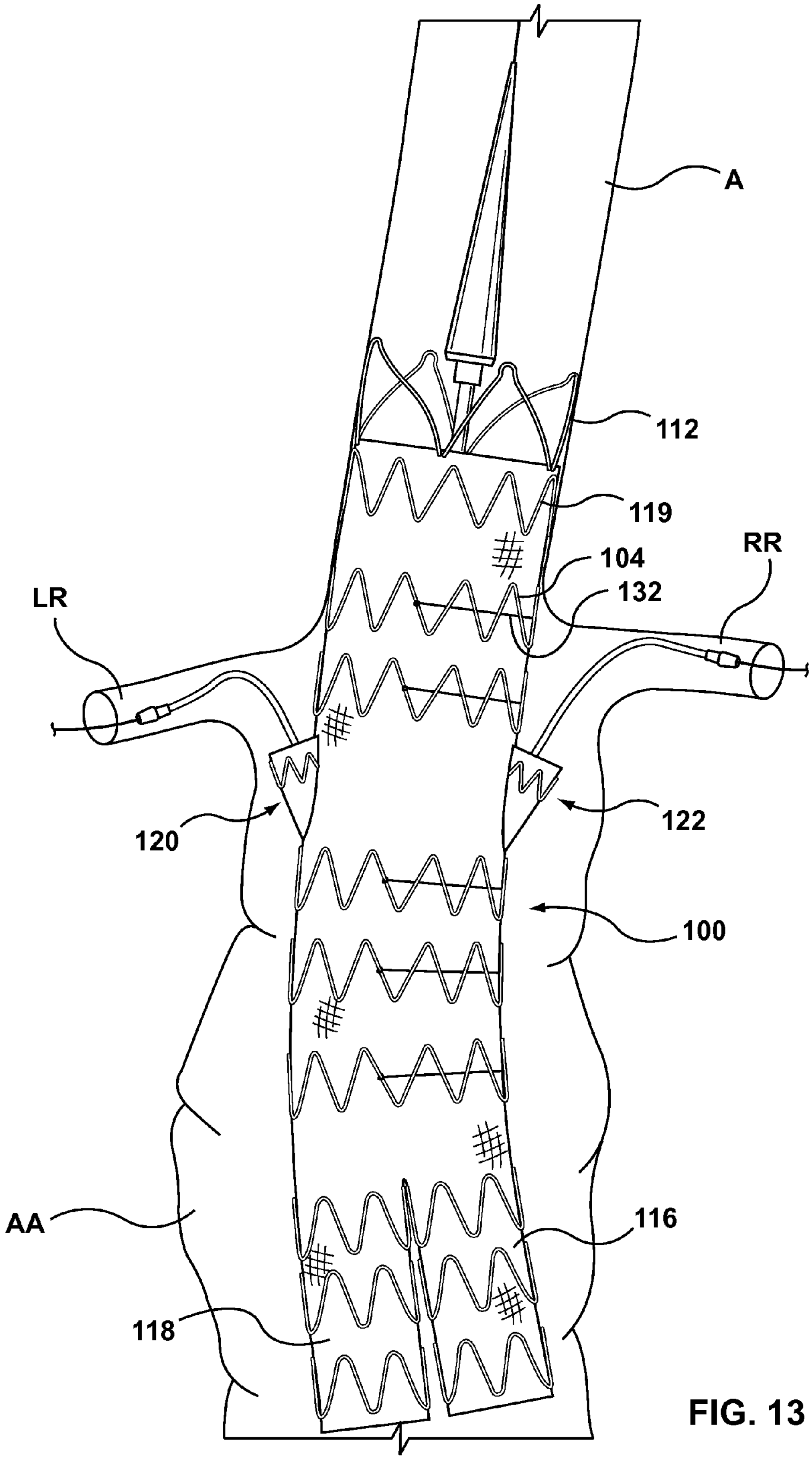

FIG. 13

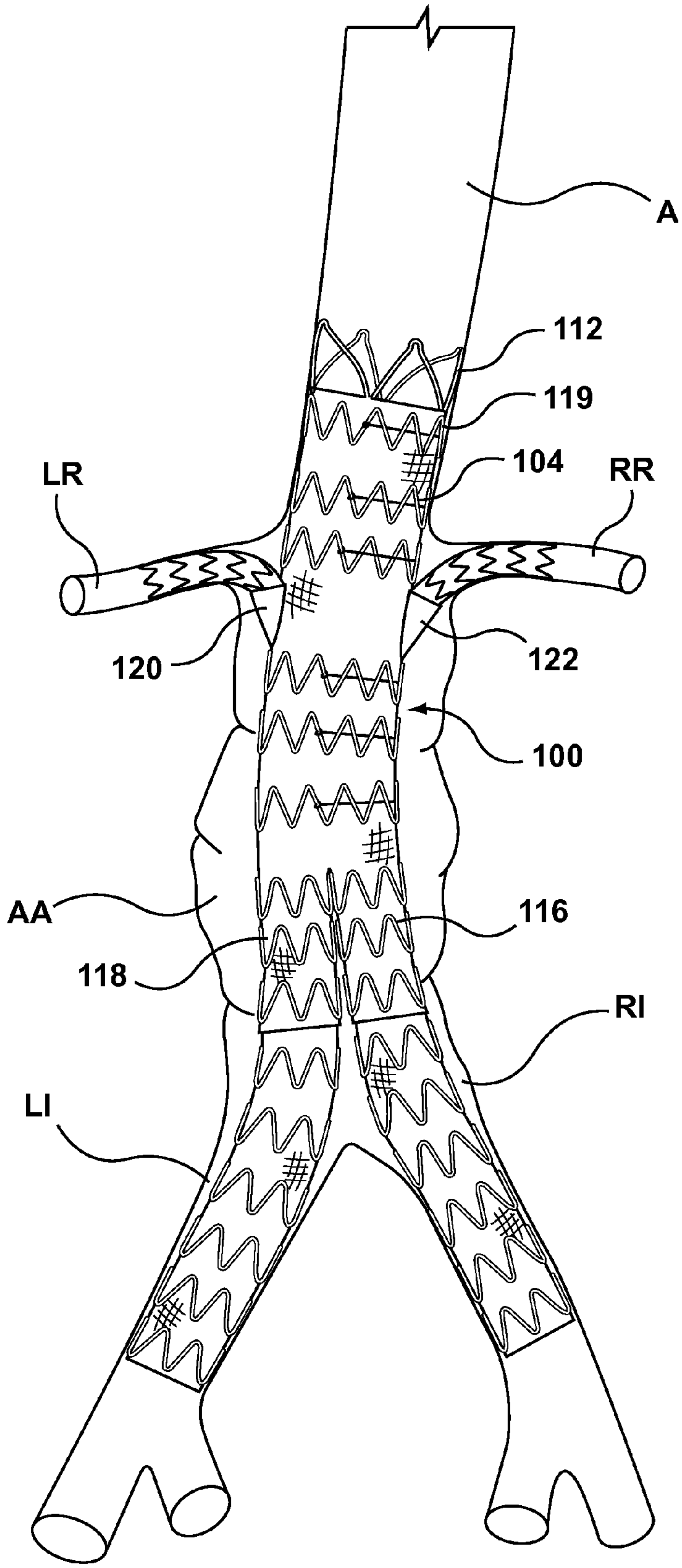

FIG. 14

CIRCUMFERENTIALLY CONSTRAINING SUTURES FOR A STENT-GRAFT

RELATED APPLICATIONS

This application is a Division of and claims the benefit of U.S. application Ser. No. 13/458,076 filed Apr. 27, 2012, now allowed, the disclosures of which are herein incorporated by reference in their entirety.

FIELD OF THE INVENTION

This invention relates generally to endoluminal medical devices and procedures, and more particularly to an endoluminal prosthesis or stent-graft having circumferentially constraining sutures to circumferentially constrain the stent-graft for a partial deployment of the stent-graft.

BACKGROUND

Aneurysms and/or dissections may occur in blood vessels, and most typically occur in the aorta and peripheral arteries. Depending on the region of the aorta involved, the aneurysm may extend into areas having vessel bifurcations or segments of the aorta from which smaller "branch" arteries extend. Various types of aortic aneurysms may be classified on the basis of the region of aneurysmal involvement. For example, thoracic aortic aneurysms include aneurysms present in the ascending thoracic aorta, the aortic arch, and branch arteries that emanate therefrom, such as subclavian arteries, and also include aneurysms present in the descending thoracic aorta and branch arteries that emanate therefrom, such as thoracic intercostal arteries and/or the suprarenal abdominal aorta and branch arteries that emanate therefrom, which could include renal, superior mesenteric, celiac and/or intercostal arteries. Lastly, abdominal aortic aneurysms include aneurysms present in the aorta below the diaphragm, e.g., pararenal aorta and the branch arteries that emanate therefrom, such as the renal arteries.

For patients with aneurysms of the aorta, surgery to replace the aorta may be performed where a portion of the aorta is replaced with a fabric substitute in an operation that uses a heart-lung machine. In such a case, the aneurysmal portion of the aorta is removed or opened and a substitute lumen is sewn across the aneurysmal portion to span it. Such surgery is highly invasive, requires an extended recovery period and, therefore, cannot be performed on individuals in fragile health or with other contraindicative factors.

When aneurysms are near branch vessels or extend into branch vessels, stent-grafts are used with fenestrations, external couplings, or other means for branch stent-grafts to be deployed into the branch vessels. The location of such fenestrations or external couplings may be critical so as not to block branch vessels. Further, when aneurysms are near branch vessels, the "landing zone" for the stent-graft may be limited such that accurate placement of the stent-graft is critical. Thus, it is desirable to be able to accurately position the stent-graft. However, stents of the stent-graft are normally designed to expand to a size larger than the target vessel to ensure apposition against the vessel wall. Thus, re-positioning the stent-graft after deployment is difficult. It is thus desirable to partially deploy the stent-graft to a diameter larger than the delivery catheter diameter, but smaller than the fully deployed diameter to enable re-positioning of the stent-graft.

Further, when aneurysms are located near branch vessels, it may be desirable to deploy the stent-graft to a diameter smaller than the fully deployed diameter in the main vessel in order to perform various actions to cannulate the branch vessels prior to completely deploying the stent-graft. Partially deploying the stent-graft allows for space outside of the stent-graft within the main vessel to perform such actions.

Devices to maintain stent-grafts in a partially deployed configuration after release from a catheter have been contemplated. However, with current devices, the stent-graft may jump out of position when the stent-graft is deployed. Accordingly, it would be desirable to minimize any movement of the stent-graft when fully deploying the stent graft by releasing the circumferentially constraining sutures.

SUMMARY OF THE INVENTION

Embodiments hereof relate to circumferentially constraining sutures for a stent-graft. The stent-graft includes a tubular body of a graft material and a plurality of stents coupled to the tubular body. The circumferentially constraining suture in a reduced diameter configuration includes a first end attached to one of the stent and extending circumferentially around a complete circumference of the tubular body, with a loop of the circumferentially constraining suture disposed opposite the first end being coupled to a trigger wire extending in a longitudinal direction along the tubular body. In a deployed configuration, the trigger wire is disengaged from the loop such that the stent radially expands and the circumferentially constraining suture extends only partially around the circumference of the tubular body.

Embodiments hereof also relate to circumferentially constraining sutures for stent-grafts. The stent-graft includes a tubular body of a graft material and a plurality of stents coupled to the tubular body. The circumferentially constraining suture includes a first thread coupled at a first end to the tubular body or one of the stents and having a first thread loop disposed opposite the first end, the first thread extending only partially around a circumference of the tubular body when the stent-graft is in a radially expanded configuration. The circumferentially constraining suture further includes a second thread having a second thread loop interlocked with the first thread loop, the second thread extending from the first thread loop around a remainder of the circumference of the tubular body. The circumferentially constraining suture is configured such that pulling the second thread causes the first thread to circumferentially constrain the tubular body such that the tubular body constricts to a reduced diameter configuration.

Embodiments hereof also relate to a method for temporarily reducing the diameter of at least a portion of a self-expanding stent-graft. The stent-graft includes a tubular body of a biocompatible graft material and a plurality of self-expanding stents. A first thread having a first thread loop and a second thread having a second thread loop are interlocked. The first thread at a first end opposite the first thread loop is attached to one of the stents. The first thread is extended around a first portion of the circumference of the tubular body and the second thread around is extended from the first thread around a second portion of the circumference of the tubular body. The second thread is pulled to cause the first loop of the first thread to move along the second portion of the circumference to reduce the diameter of the tubular body. A trigger wire is inserted longitudinally along the

tubular body and through the first loop to retain the tubular body in a reduced diameter configuration after the second thread is removed.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a perspective view of a main vessel stent-graft including circumferentially constraining sutures according to an embodiment hereof, wherein the main vessel stent-graft in radially expanded configuration.

FIG. **2** is a schematic illustration of a circumferentially constraining suture.

FIG. **2**A is a schematic illustration of a circumferentially constraining suture.

FIG. **3** is zoomed in view of a portion of the stent-graft prosthesis of FIG. **1** where an end of a first thread of a circumferentially constraining suture is attached to a stent and an end of a second thread of the circumferentially constraining suture exits the stent.

FIGS. **3**A-**3**C are schematic illustrations of embodiments of the first end of a first thread attached to a strut of a stent.

FIG. **4** is zoomed in view of a portion of the stent-graft of FIG. **1** where the first thread and the second thread are interlocked.

FIG. **5** is a schematic illustration of a circumferentially constraining suture of the stent-graft of FIG. **1** with the second thread pulled to tighten the first thread around the stent-graft.

FIG. **6** is a schematic illustration of a trigger wire being inserted through a first thread loop of a circumferentially constraining suture.

FIG. **7** is a schematic illustration of the stent graft prosthesis of FIG. **1** in a reduced diameter configuration with the trigger wire extending through the first thread loop of each circumferentially constraining suture.

FIGS. **8**-**14** schematically illustrate a method of delivering the main vessel stent-graft of FIG. **1** to a target site in the abdominal aorta, partial deployment of the stent-graft, and full deployment of the stent-graft after release of the circumferentially constraining sutures.

DETAILED DESCRIPTION

Specific embodiments of the present invention are now described with reference to the figures, wherein like reference numbers indicate identical or functionally similar elements. Specific embodiments are now described with reference to the figures, wherein like reference numbers indicate identical or functionally similar elements. Unless otherwise indicated, for the delivery system the terms "distal" and "proximal" are used in the following description with respect to a position or direction relative to the treating clinician. "Distal" and "distally" are positions distant from or in a direction away from the clinician, and "proximal" and "proximally" are positions near or in a direction toward the clinician. For the stent-graft prosthesis proximal is the portion nearer the heart by way of blood flow path while distal is the portion of the stent-graft further from the heart by way of blood flow path. In addition, the term "self-expanding" is used in the following description with reference to one or more stent structures of the prostheses hereof and is intended to convey that the structures are shaped or formed from a material that can be provided with a mechanical memory to return the structure from a compressed or constricted delivery configuration to an expanded deployed configuration. Non-exhaustive exemplary self-expanding materials include stainless steel, a pseudo-elastic metal such as a nickel titanium alloy or nitinol, various polymers, or a so-called super alloy, which may have a base metal of nickel, cobalt, chromium, or other metal. Mechanical memory may be imparted to a wire or stent structure by thermal treatment to achieve a spring temper in stainless steel, for example, or to set a shape memory in a susceptible metal alloy, such as nitinol. Various polymers that can be made to have shape memory characteristics may also be suitable for use in embodiments hereof to include polymers such as polynorborene, trans-polyisoprene, styrene-butadiene, and polyurethane. As well poly L-D lactic copolymer, oligo caprylactone copolymer and poly cyclo-octine can be used separately or in conjunction with other shape memory polymers.

The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Although the description of the invention is in the context of treatment of blood vessels such as aorta, the invention may also be used in any other blood vessels and body passageways where it is deemed useful. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary or the following detailed description.

With reference to FIGS. **1**-**7**, a self-expanding main vessel endovascular prosthesis or stent-graft **100** is configured for placement in a vessel such as the abdominal aorta. In the particular embodiment shown, main vessel stent-graft **100** is a bifurcated stent-graft configured to treat short-neck infrarenal, juxtarenal, and/or suprarenal aneurysms in a wide range of patient anatomies. However, the invention is not so limited and may also be used for stent-grafts for use in other areas and without all of the features described below.

FIG. **1** illustrates a perspective view of main vessel stent-graft **100** in a radially expanded configuration prior to placement within a delivery catheter. In this application, the terms "radially expanded configuration" and "deployed configuration" are used to describe the stent-graft when it is not in a delivery catheter and without circumferentially constraining sutures (described below) restricting the expansion of the stents of the stent-graft prosthesis. However, it would be recognized by those skilled in the art that the "radially expanded configuration" and the "deployed configuration" may not be exactly the same diameter because at least some of the stents of the stent-graft may be oversized to ensure a tight seal of the stent-graft to the vessel wall. Accordingly, the "deployed configuration" may be smaller than the "radially expanded configuration" in practice due to the vessel wall restricted expansion of the stents. However, for purposes of this application, the terms generally mean that there are no outside forces (other than the vessel wall) restricting expansion of the stent-graft prosthesis. Stent-graft **100** includes a generally tubular or cylindrical graft or body **102** that defines a lumen **107** and has a first edge or end **106** and a second edge or end **108**. Tubular graft **102** may be formed from any suitable graft material, for example and not limited to, a low-porosity woven or knit polyester, DACRON material, expanded polytetrafluoroethylene, polyurethane, silicone, ultra high molecular weight polyethylene, or other suitable materials. In another embodiment, the graft material could also be a natural material such as pericardium or another membranous tissue such as intestinal submucosa. A plurality of stents **104** are coupled to graft **102**. Stents **104** may be coupled to graft **102** by stitching **110** or by other means known to those skilled in the art. In the embodiment shown, stents **104** are coupled to an outside surface of graft **102**, but stents **104** may alternatively be coupled to an inside surface of graft **102**.

An anchor stent **112** is coupled to graft **102** adjacent first end **106** of graft **102**. Anchor stent **112** is a radially-compressible ring or scaffold that is operable to self-expand into apposition with an interior wall of a body vessel (not shown). Anchor stent **112** is constructed from a self-expanding or spring material, such as nitinol, and is a sinusoidal patterned ring including a plurality of crowns or bends **113**A, **113**B and a plurality of struts or straight segments **115** with each crown being formed between a pair of opposing struts. Anchor stent **112** is coupled to the graft material so as to have a first or proximal-most set of crowns **113**A that extend outside of or beyond first edge **106** of graft **102** in an open web or free-flow configuration and a second or opposing set of crowns **113**B that is coupled to first edge **106** of tubular graft **102**. Crowns **113**B are coupled to tubular graft **102** by stitches or other means known to those of skill in the art. In the embodiment shown, crowns **113**B are coupled to an outside surface of tubular graft **102**. However, crowns **113**B may alternatively be coupled to an inside surface of tubular graft **102**. Unattached or free crowns **113**A may include barbs **114** for embedding into and anchoring into vascular tissue when stent-graft prosthesis **100** is deployed in situ. In an embodiment, anchor stent **112** may be the Endurant II™ suprarenal stent, manufactured by Medtronic, Inc., of Minneapolis, Minn.

A scallop **117** cut out or removed from graft **102** at proximal or first end **106**. Scallop **117** is an open-topped fenestration. When deployed in situ, scallop **117** is positioned within the aorta distal of the superior mesenteric artery (SMA) and extends around and/or frames the ostium of the SMA. In short-neck infrarenal, juxtarenal, and/or suprarenal aneurysms, first edge **106** of tubular graft **102** is deployed within the abdominal aorta at or near the superior mesenteric artery (SMA). In order to avoid blockage of blood flow into the superior mesenteric artery (SMA), stent-graft **100** is positioned or oriented within the abdominal aorta such that scallop **117** is positioned around the ostium of the superior mesenteric artery (SMA) and the graft material of tubular graft **102** does not occlude the ostium of the SMA. The presence of scallop **117** for the SMA allows for main vessel stent-graft **100** to deploy and seal against a sufficient length, i.e., greater than 10 mm, of healthy or non-aneurysmal tissue distal to the SMA for patients suffering from short-neck infrarenal, juxtarenal, and/or suprarenal aneurysms.

A seal stent **119** is coupled to graft **102** at first end **106**. Seal stent **119** is configured to accommodate scallop **117**. Seal stent **119** is a radially-compressible ring or scaffold that is coupled to tubular graft **102** for supporting the graft material and is operable to self-expand into apposition with an interior wall of a blood vessel (not shown). Seal stent **119** is constructed from a self-expanding or spring material, such as nitinol, and is a sinusoidal patterned ring including a plurality of crowns or bends and a plurality of struts or straight segments with each crown being formed between a pair of opposing struts. Seal stent **119** is coupled to tubular graft **102**, immediately distal of first end **106** thereof and distal of anchor stent **112**. Seal stent **119** is coupled to tubular graft **102** by stitches or other means known to those of skill in the art. In the embodiment shown, seal stent **119** is coupled to an outside surface of tubular graft **102**, but seal stent **119** may alternatively be coupled to an inside surface of tubular graft **102**. Seal stent **119** includes at least two struts that are lengthened or elongated with respect to the remaining struts to accommodate scallop **117**.

In the embodiment shown, stent-graft **100** includes a first tubular leg or extension **116** and a second tubular leg or extension **118**, each extending from second end **108**. Legs **116**, **118** define lumens that are in fluid communication with lumen **107** of tubular graft **102**. In an embodiment, legs **116**, **118** are integrally formed with tubular graft **102** as a unitary graft component and thus are formed from the same material as tubular graft **102**. In another embodiment, legs **116**, **118** may be formed separately from tubular graft **102** and coupled thereto. In the embodiment shown, legs **116**, **118** are of equal length and are oriented anterior and posterior within the abdominal aorta when deployed in the abdominal aorta.

Stent-graft **100** also includes couplings **120**, **122** for connecting stent-graft **100** to branch vessel prostheses (not shown) to accommodate the left and right renal arteries, respectively. Tubular graft **102** includes opposing fenestrations or openings formed through a sidewall of the graft material. Couplings **120**, **122** are disposed on an outside surface of main vessel stent-graft **100** corresponding to openings in tubular graft **102**. Couplings **120**, **122** may be generally cylindrically shaped or frustoconically shaped. Couplings **120**, **122** include coupling graft material. The graft material of couplings **120**, **122** may be the same type of graft material as the graft material of tubular graft **102** or it may be a different material. Also, in the embodiment shown, couplings **120**, **122** are separate components that are attached to tubular graft **102**. However, it would be understood by those of ordinary skill in the art that couplings **120**, **122** may be formed as a continuation of tubular graft **102**. Couplings **120**, **122** include self-expanding support stents or sinusoidal rings **124**, **126**, respectively, coupled to the coupling graft material. Support stents **124**, **126** are constructed from a self-expanding or spring material, such as nitinol, and is a sinusoidal patterned ring including a plurality of crowns or bends and a plurality of struts or straight segments with each crown being formed between a pair of opposing struts. In an embodiment, support stents **124**, **126** are four peak stents and thus include eight crowns, although it will be apparent to one of ordinary skill in the art that the support stent may include more or less crowns. Other embodiments of couplings **124**, **126** may be used as would be understood by those skilled in the art.

Although stent-graft **100** has been described generally above, more details of stent-graft **100** may be found in U.S. patent application Ser. Nos. 13/458,209 and 13/458,242 to Coghlan et al., filed Apr. 27, 2012 (now published as U.S. Pub. Nos. 2013/0289701 A1 and 2013/0289702 A1), herein incorporated by reference in their entirety. Further, although stent-graft **100** has been described with the particular features described above, the circumferentially constraining sutures described below may be used with any stent-graft where it is desirable to have a staged deployment of the stent-graft prosthesis.

As described above, FIG. **1** shows stent-graft **100** in a radially expanded configuration prior to placement within a delivery catheter for delivery to a treatment site. In the embodiment shown, five circumferentially constraining sutures **130** are disposed around stent-graft **100**. Circumferentially constraining sutures **130**, when utilized as described in more detail below, reduce the diameter of stent-graft prosthesis **100** by about 40 to 70 percent from the radially expanded configuration. However, stent-graft **100** in the reduced diameter configuration has a diameter about 40 to 50 percent larger than in a delivery configuration wherein stent-graft **100** is disposed within a sleeve of a delivery catheter. Those of ordinary skill in the art would recognize that by adjusting the length of the threads of the circumferentially constraining sutures, as described in more detail below, the reduction in the diameter of stent-graft prosthesis by the circumferentially constraining sutures may be varied outside of the ranges noted above.

In the embodiment shown, circumferentially constraining sutures **130** are disposed around the graft material of tubular graft **102** adjacent five of stents **104**. As explained in more detail below, anchor stent **112** is held by a tip capture mechanism during delivery and partial deployment of stent-graft **100**. The tip capture mechanism holds proximal-most crowns **113**A of anchor stent **112** in a reduced diameter configuration after retraction of the outer sheath or sleeve covering stent-graft **100**, as known to those skilled in the art. Thus, anchor stent **112** and seal stent **119** do not include circumferentially constraining sutures because they do not fully deploy due to the tip capture mechanism. However, as would be understood by those skilled in the art, more or less circumferentially constraining sutures **130** may be utilized depending on the number of stents **104** coupled to tubular graft **102**, the particular application and procedure, and the locations where it is desirable to have a reduced diameter.

Each circumferentially constraining suture **130** comprises a first thread or string **132** interlocked with a second thread or string **134** at interlocking location **140**. First thread **132** is formed into a first thread loop **136** by having a first end **146** and a second end **147** of first thread **132** disposed tied to each other at knot **137**, as shown in FIG. **2**. Essentially, first thread **132** is folded back at approximately a mid-point thereof to form a first thread loop **136**. First thread **132** has a first thread length FL that is less than the circumference of stent-graft **100**. In particular, first thread length FL may be between 30% and 60% of the circumference of stent-graft **100**. Similarly, second thread **134** is folded back at approximately a mid-point thereof to form a second thread loop **138**, as shown in FIG. **2**. As explained above, first thread length FL may be shorter to make the reduced diameter smaller and first thread length FL may be longer to make the reduced diameter larger. First thread loop **136** and second thread loop **138** are interlocked with each other at **140** as shown in FIG. **2**. As also shown in FIG. **2**, ends **142** and **143** of second thread **134** disposed opposite second thread loop **138** are tied or otherwise attached to a pull tab **144**. Pull tab **144** as shown is a circular, donut shaped tab with ends **142**, **143** of second thread **134** tied to pull tab **144**. However, those of ordinary skill in the art would recognize that other pull tabs may be used, or a large knot tied in ends **142**, **143** may function as a pull tab. Further, those of ordinary skill in the art would recognize that other ways of forming first and second threads with interlocked first and second thread loops may be used. For example, and not by way of limitation, FIG. **2**A shows first end **246** of first thread **232** that may be attached to strut **105** (see FIG. **3**C described below), and second end **247** may form a first thread loop **232** by forming a loop and tying second end **247** to first thread **232** and **245**. Similarly, one end **242** of second thread **234** may be tied to pull tab **244** and the other end **243** of second thread **234** may form a loop **238** and be tied to second thread **234** at **245**. Other ways of forming first and second thread loops may be used, as known to those skilled in the art. First thread **132**, **232** and second thread **134**, **234** may be monofilament or braided and formed of polyester, ultra high molecular weight polyethelene (UHMWPE), polypropylene, or other alternate thread materials known to those skilled in the art.

In the embodiment shown, first and second ends **146**, **147** of first thread **132** are tied to each other to form first thread loop **136**, and first thread loop **136** is tied to a strut **105** of a stent **104**, as shown in detail in FIG. **3**A. First thread **132** then extends between stent **104** and the graft material of body **102**, as shown in FIGS. **3** and **4**. First thread **132** also extends between stitches **110** which attach stent **104** to the graft material of body **102**, thereby keeping first thread **132** from moving longitudinally along stent-graft prosthesis **100**. First thread **132** is interlocked with second thread **134**, which also extends circumferentially around graft material **102** between the graft material and stent **104**, as shown in FIG. **4**. Other ways of forming first thread loop **136** and of attaching first thread loop **136** to stent **104** may be utilized, as would be recognized by those skilled in the art. For example, and not by way of limitation, ends **146**, **147** of first thread **132** may be tied to each other around strut **105**, as shown in FIG. **3**B. Further, using the first thread loop **234** shown in FIG. **2**A, first end **246** of first thread may be tied around strut **105** at knot **248** and first thread loop **236** is disposed at the opposite end of knot **248** by having second end **247** form loop **236** and then tying second end **247** to first thread **232**, as shown in FIG. **3**C.

Circumferentially constraining sutures **130** function to circumferentially constrain stent-graft **100**, as will be described with reference to FIGS. **5**-**7**. First, as shown in FIG. **5**, second thread **134** is pulled by pulling on pull tab **144**. Because first thread **132** is attached to a body stent **104** at an end opposite first thread loop **136**, and second thread **134** is disposed between graft **102** and stents **104**, pulling second thread **134** causes first thread to continue around the circumference of stent-graft **100**, following the path of second thread **134** until the location where pull tab **144** was initially located. At that point, pulling second thread **134** causes first thread to continue following second thread **134**, but first thread loop **136** may extend radially away from stent-graft **100**, as shown in FIG. **5**. Further, because first thread **132** is fixed to a stent **104** at **148**, pulling second thread **134** and first thread **132** along with it causes first thread **132** to circumferentially close or tighten or shrink stent-graft **100** in the area of circumferentially constraining suture **130**, as also shown in FIG. **5**.

Next, as shown in FIG. **6**, a release or trigger wire **150** extending generally longitudinally along stent-graft **100** is inserted through first thread loop **136**. The steps of FIGS. **5** and **6** are repeated for each circumferentially constraining suture **130** of stent-graft **100**. Preferably, the same trigger wire **150** is used for all the circumferentially constraining sutures, but it is not necessary. Although FIGS. **5** and **6** show the middle circumferentially constraining suture **130**, it would be understood that with a single trigger wire **150**, it is preferable to proceed from either the proximal-most or the distal-most circumferentially constraining suture **130** and proceed either distally or proximally, respectively, with trigger wire **150** advancing along either distally or proximally, respectively, to engage each first thread loop **136** of each first thread **132**.

When each first thread loop **136** of each first thread **132** is engaged by trigger wire **150**, each second thread **134** may be removed. This causes the stent **104** associated with the circumferentially constraining suture to try to expand to its radially expanded diameter. However, because trigger wire **150** holds first threaded loop **136** at the location where second thread **134** exited from between graft **102** and the stent **104**, and the first thread length FL of first thread **132** is fixed and is less than the circumference of stent-graft **100**, trigger wire **150** holds stent-graft **100** in a reduced diameter configuration. It is preferable that pull tab **144** is located adjacent knot **148**, as shown in FIG. **3**. In other words, it is preferable that when trigger wire **150** holds circumferentially constraining suture **130** such that stent-graft **100** is in the reduced diameter configuration, first thread **132** extends completely around the circumference of stent-graft **100**. In such an embodiment, the first thread length FL of first thread **132** determines the amount that the circumferentially constraining suture **130** reduces the diameter of stent-graft **100**. Further, in such an embodiment, the circumferentially constraining suture **130** constrains stent-graft **100** around the entire circumference of stent-graft **100**, thereby applying equal restraining force around the circumference of the stent-graft to minimize movement of the stent-graft when releasing stent graft prosthesis **100** from the circumferentially constraining sutures **130** by removing the trigger wire **150**.

After the trigger wire **150** is disposed through first thread loop **136** of each circumferentially constraining suture **130**, second thread **134** can be removed such as by cutting second thread loop **138**. This leaves stent-graft **100** in the reduced diameter configuration with trigger wire **150** disposed through each first thread loop **136** of each first thread **132** of each circumferentially constraining suture **130**, as shown in FIG. **7**. Trigger wire **150** extends within a delivery catheter to a handle of the delivery catheter such that a user may pull trigger wire **150** to release each circumferentially constraining suture **130** such that stent-graft prosthesis **100** may expand to its deployed configuration, as described in more detail below. Trigger wire **150** may be any suitable wire formed of any suitable material. For example, and not by way of limitation, trigger wire may be formed of nitinol, and may have a diameter in the range of 0.010 to 0.014 inch. However, it is understood that different materials and different sizes can be used provided that the trigger wire can perform the functions described herein of holding first thread **132** to maintain the stent-graft in a reduced diameter configuration and of releasing the circumferentially constraining suture by retraction of the trigger wire without excessive force by the user.

Stent-graft **100** can then be disposed within a delivery catheter as known to those skilled in the art. After delivery to a target site and partial deployment of stent-graft prosthesis **100** from a sheath or outer cover of the delivery system, trigger wire **150** may be retracting proximally (i.e., towards the clinician) to release circumferentially constraining sutures **130** and allow stent-graft prosthesis **100** to fully deploy to its radially expanded or deployed configuration, as described in more detail below. With second thread **134** removed from each circumferentially constraining suture **130**, only first thread **132** remains. The drawings and description regarding delivery and deployment of the stent-graft **100** may refer to first thread **132** and circumferentially constraining suture **130** interchangeably.

FIG. **8** shows a main vessel delivery system **882**, with main vessel stent-graft **100** compressed therein, advanced over a main vessel guide wire **884** and to the target site in the abdominal aorta A. Guide wire **884** is typically inserted into the femoral artery and routed up through the left iliac artery LI to abdominal aorta, as is known in the art. FIGS. **8-14** show a posterior view of the aorta A and the vessels that branch therefrom. Accordingly, the superior mesenteric artery (SMA), for example, is shown exiting the anterior side of the aorta opposite the posterior side shown in the drawings, and is therefore shown in phantom where blocked by the aorta. FIGS. **8-14** show similar devices as those shown and described in co-pending U.S. patent application Ser. Nos. 13/457,535 and 13/457,544 to Maggard et al., filed Apr. 27, 2012 (now published as U.S. Pat. Pub. Nos. 2013/0289696 A1 and 2013/0289693 A1, respectively); U.S. patent application Ser. Nos. 13/457,537 and 13/457,541 to Argentine et al., filed Apr. 27, 2012 (now published as U.S. Pat Pub Nos. 2013/0289691 A1 and 2013/0289692 1, respectively); and U.S. patent application Ser. Nos. 13/458,209 and 13/458,242 to Coghlan et al., filed Apr. 27, 2012 (now published as U.S. Pat. Pub. Nos. 2013/0289701 A1 and 2013/0289702 A1), herein incorporated by reference in their entirety. However, in the above-identified applications, the views of the delivery and deployment of the stent-graft prosthesis are anterior views of the aorta. Delivery system **882** is fully described in co-pending U.S. patent application Ser. Nos. 13/457,535 and 13/457,544 to Maggard et al., filed Apr. 27, 2012 (now published as U.S. Pat. Pub. Nos. 2013/0289696 A1 and 2013/0289693 A1, respectively); and U.S. patent application Ser. Nos. 13/457,537 and 13/457,541 to Argentine et al., filed Apr. 27, 2012 (now published as U.S. Pat. Pub. Nos. 2013/0289691 A1 and 2013/0289692 A1, respectively), herein incorporated by reference in their entirety. Main vessel stent-graft prosthesis **100** is mounted on a catheter shaft **988** (see FIG. **9**) of the delivery system and an outer delivery sheath **886** of the delivery system covers and restrains main vessel stent-graft prosthesis **100** in a radially compressed delivery configuration for delivery thereof. As will be understood by those of ordinary skill in the art, delivery system **882** may include a tip capture mechanism (not shown) which engages the proximal-most set of crowns of anchor stent **112** until retraction of the tip capture mechanism releases the proximal-most set of crowns for final deployment of main vessel stent-graft prosthesis **100**.

FIG. **9** illustrates a first or initial step to deploy main vessel stent-graft prosthesis **100** in which outer delivery sheath **886** of delivery system **882** is retracted to release or uncover a proximal end portion of main vessel stent-graft prosthesis **100**. When first released from the delivery system, the proximal end portion may be positioned such that scallop **117** (not shown in FIG. **9**) is below the target site of the superior mesenteric artery (SMA). The proximal-most set of crowns of anchor stent **112** is captured or restrained by the tip capture mechanism of delivery system **882**. Delivery sheath **886** is retracted to expose at least seal stent **119**. In the embodiment of FIG. **9**, delivery sheath **886** is shown as retracted to expose a body stent **104**.

As described in co-pending U.S. patent application Ser. Nos. 13/457,535 and 13/457,544 to Maggard et al., filed Apr. 27, 2012 (now published as U.S. Pat. Pub. Nos. 2013/0289696 A1 and 2013/0289693 A1, respectively); U.S. patent application Ser. Nos. 13/457,537 and 13/457,541 to Argentine et al., filed Apr. 27, 2012 (now published as U.S. Pat. Pub. Nos. 2013/0289691 and 2013/0289692 A1, respectively); and U.S. patent application Ser. Nos. 13/458,209 and 13/458,242 to Coghlan et al., filed Apr. 27, 2012 (now published as U.S. Pat. Pub. Nos. 2013/0289701 A1 and 2013/0289702 A1), previously incorporated by reference in their entirety, the superior mesenteric artery (SMA) is cannulated and the main vessel stent-graft **100** is repositioned to align scallop **117** with the superior mesenteric artery (SMA). The terms "cannulation" and "cannulate" are used herein with reference to the navigation of a guidewire and guide catheter into a target vessel.

With the proximal end portion of main vessel stent-graft **100** now positioned as desired, delivery sheath **886** is shown retracted in FIG. **10** to expose at least couplings **120**, **122** of main vessel stent-graft prosthesis **100**. Anchor stent **112** is still captured or restrained by the tip capture mechanism of delivery system **882** such that the proximal end portion of stent-graft **100** does not fully deploy. Further, first threads **132** of circumferentially constraining sutures **130** prevent the stent-graft prosthesis **100** from fully deploying in the areas that have been released from sheath **886**. These areas radially expand from the delivery configuration to a reduced diameter configuration that is radially larger than the delivery configuration but 30 to 60% smaller in diameter than the deployed configuration, as explained above.

The renal arteries, right renal artery RR and left renal artery LR, are then cannulated, as described in co-pending U.S. patent application Ser. Nos. 13/457,535 and 13/457,544 to Maggard et al., filed Apr. 27, 2012 (now published as U.S. Pat. Pub. Nos. 2013/0289696 A1 and 2013/0289693 A1, respectively); U.S. patent application Ser. Nos. 13/457,537 and 13/457,541 to Argentine et al., filed Apr. 27, 2012 (now published as U.S. Pat. Pub. Nos. 2013/0289691 A1 and 2013/0289692 A1, respectively); and U.S. patent application Ser. Nos. 13/458,209 and 13/458,242 to Coghlan et al., filed Apr. 27, 2012 (now published as U.S. Pat. Pub. Nos. 2013/0289701 A1 and 2013/0289702 A1), previously incorporated by reference in their entirety. The renal arteries are cannulated while sheath **886** is partially retracted as shown in FIG. **10**. After the renal arteries have been cannulated, the sheath **886** is fully retracted to release stent-graft **100** from sheath **886** and the branch vessel prosthesis delivery systems are advanced into the renal arteries. This leaves main vessel stent-graft **100** partially deployed in a reduced diameter configuration due to first threads of circumferentially constraining sutures **130**, as shown in FIG. **11**.

Trigger wire **150** is then retracted proximally (i.e. towards the physician), as shown by the arrow in FIG. **12**. As trigger wire **150** moves past stents **104**A and **104**B, first threads **132**A and **132**B of circumferentially constraining sutures are released, allowing that portion of stent-graft **100** to expand to the deployed configuration. First threads **132**A, **132**B remain attached at one end to stents **104**A, **104**B, respectively, as described above and shown at **148**A, and first threads **132**A, **130**B extend between graft **102** and stents **104**A, **104**B. Because first threads **132**A and **132**B are each shorter than the circumference of the deployed stent-graft prosthesis **100**, each first thread **132**A, **132**B extends only partially around the circumference of stent-graft prosthesis **100**. Further, since first thread loop **136** (not shown in FIG. **12**) of first threads **132**A, **132**B is not attached to trigger wire **150** or any portion of stent-graft prosthesis **100**, first and second threads **132**A, **132**B do not exert a radial force to constrain stent-graft **100** in a reduced diameter configuration. As trigger wire **150** continues to be retracted proximally, the remaining first threads **132**C, **132**D, **132**E of the respective circumferentially constraining sutures **130** are released, thereby allowing stent-graft **100** to fully deploy, as shown in FIG. **13**. In addition, anchor stent **112** may be released from the tip capture mechanism of the delivery system **882**, as also shown in FIG. **13**. When anchor stent **112** is released from delivery system **882**, seal stent **119** fully expands and conformingly engages and seals the edges of scallop **117** with the blood vessel inner wall. Trigger wire **150** for circumferentially constraining sutures **130** may also be used as a capture mechanism (not shown) as described in co-pending U.S. patent application Ser. Nos. 13/457,535 and 13/457,544 to Maggard et al., filed Apr. 27, 2012 (now published as U.S. Pat. Pub. Nos. 2013/0289696 A1 and 2013/0289693 A1, respectively); and U.S. patent application Ser. Nos. 13/457,537 and 13/457,541 to Argentine et al., filed Apr. 27, 2012 (now published as U.S. Pat. Pub. Nos. 2013/0289691 A1 and 2013/0289692 A1, respectively), previously incorporated by reference herein in their entirety.

The branch vessel stent-graft prostheses may then be deployed within right renal artery RR and left renal artery LR, respectively, by retracting outer sheaths of the branch vessel stent-graft delivery systems, as known to those skilled in the art and described in co-pending U.S. patent application Ser. Nos. 13/457,535 and 13/457,544 to Maggard et al., filed Apr. 27, 2012 (now published as U.S. Pat. Pub. Nos. 2013/0289696 A1 and 2013/0289693 A1, respectively); U.S. patent application Ser. Nos. 13/457,537 and 13/457,541 to Argentine et al., filed Apr. 27, 2012 (now published as U.S. Pat. Pub. Nos. 2013/0289691 A1 and 2013/0289692 A1, respectively); and U.S. patent application Ser. Nos. 13/458,209 and 13/458,242 to Coghlan et al., filed Apr. 27, 2012 (now published as U.S. Pat. Pub. Nos. 2013/0289701 A1 and 2013/0289702 A1), previously incorporated by reference in their entirety. Further, limb prostheses may be delivered and deployed within legs **116**, **118** of main vessel stent-graft prosthesis **100**, extending into right iliac artery RI and left iliac artery LI, respectively, as shown in FIG. **14**. All the delivery systems are removed, leaving the main vessel stent-graft **100**, the branch vessel prostheses, and the limb prostheses, as shown in FIG. **14**.

While various embodiments according to the present invention have been described above, it should be understood that they have been presented by way of illustration and example only, and not limitation. It will be apparent to persons skilled in the relevant art that various changes in form and detail can be made therein without departing from the spirit and scope of the invention. It will also be understood that each feature of each embodiment discussed herein, and of each reference cited herein, can be used in combination with the features of any other embodiment. All patents and publications discussed herein are incorporated by reference herein in their entirety.

What is claimed is:

1. A method of temporarily reducing the diameter of at least a portion of a self-expanding endovascular prosthesis, the prosthesis comprising a tubular body of a biocompatible graft material and a self-expanding stent, the method comprising the steps of:

interlocking a first thread having a first thread loop with a second thread having a second thread loop;

attaching the first thread at a first end opposite the first thread loop to the tubular body;

extending the first thread around a first portion of a circumference of the tubular body and the second thread around a second portion of the circumference of the tubular body;

pulling the second thread to cause the first loop of the first thread to move along the second portion of the circumference to reduce the diameter of the tubular body; and

after the pulling of the second thread to reduce the diameter of the tubular body, inserting a trigger wire through the first thread loop.

2. The method of claim **1**, further comprising the step of removing the second thread after the trigger wire is inserted through the first thread loop.

3. The method of claim **1**, wherein the step of attaching the first end of the first thread loop to the tubular body comprises tying the first thread to the stent.

4. The method of claim **1**, wherein the step of attaching the first end of the first thread loop to the tubular body comprises tying the first end to a strut of the stent.

5. The method of claim **1**, wherein the step of attaching the first end of the first thread loop to the tubular body comprises wrapping a portion of the first thread loop around a strut of the stent and pulling the remainder of the first thread loop through the portion of the first thread loop wrapped around the strut.

6. The method of claim **1**, wherein the second thread includes a pull tab disposed at a first end of the second thread opposite the second thread loop and where the step of pulling the second thread comprises pulling the pull tab.

7. The method of claim **1**, wherein the step of inserting the trigger wire through the first thread loop comprises inserting the trigger wire in a longitudinal direction relative to the tubular body.

8. The method of claim **1**, wherein the self-expanding endovascular prosthesis comprises a plurality of self-expanding stents, a plurality of first threads having first thread loops, and a plurality of second threads having second thread loops,

wherein the steps of interlocking, attaching, extending, and pulling comprise performing these steps with each of the plurality of first threads and second threads corresponding to a respective one of the plurality of self expanding stents, and

wherein the step of inserting a trigger wire through the first thread loop comprises inserting the trigger wire through each of the first thread loops.

9. A method of temporarily reducing the diameter of at least a portion of a self-expanding endovascular prosthesis, the prosthesis comprising a tubular body of a biocompatible graft material and a self-expanding stent, the method comprising the steps of:

directly interlocking a first thread having a first thread loop with a second thread having a second thread loop;

attaching the first thread at a first end opposite the first thread loop to the tubular body;

extending the first thread around a first portion of a circumference of the tubular body and the second thread around a second portion of the circumference of the tubular body;

pulling the second thread to cause the first loop of the first thread to move along the second portion of the circumference to reduce the diameter of the tubular body; and

inserting a trigger wire through the first thread loop.

10. The method of claim **9**, further comprising the step of removing the second thread after the trigger wire is inserted through the first thread loop, wherein the trigger wire and the first thread maintain the reduced diameter of the tubular body.

11. The method of claim **9**, wherein the step of attaching the first end of the first thread loop to the tubular body comprises attached the first thread to the stent.

12. The method of claim **9**, wherein the second thread includes a pull tab disposed at a first end of the second thread opposite the second thread loop and where the step of pulling the second thread comprises pulling the pull tab.

13. The method of claim **9**, wherein the step of inserting the trigger wire through the first thread loop comprises inserting the trigger wire in a longitudinal direction relative to the tubular body.

14. The method of claim **9**, wherein the self-expanding endovascular prosthesis comprises a plurality of self-expanding stents, a plurality of first threads having first thread loops, and a plurality of second threads having second thread loops,

wherein the steps of directly interlocking, attaching, extending, and pulling comprise performing these steps with each of the plurality of first threads and second threads corresponding to a respective one of the plurality of self expanding stents, and

wherein the step of inserting a trigger wire through the first thread loop comprises inserting the trigger wire through each of the first thread loops.

15. A method of temporarily reducing the diameter of at least a portion of a self-expanding endovascular prosthesis, the prosthesis comprising a tubular body of a biocompatible graft material and a self-expanding stent, the method comprising the steps of:

interlocking a first thread having a first thread loop with a second thread having a second thread loop;

attaching the first thread at a first end opposite the first thread loop to the tubular body;

extending the first thread around a first portion of a circumference of the tubular body and the second thread around a second portion of the circumference of the tubular body;

pulling the second thread to cause the first loop of the first thread to move along the second portion of the circumference to reduce the diameter of the tubular body; and

inserting a trigger wire through the first thread loop and not through the second thread loop.

16. The method of claim **15**, further comprising the step of removing the second thread after the trigger wire is inserted through the first thread loop, wherein the trigger wire and the first thread maintain the reduced diameter of the tubular body.

17. The method of claim **15**, wherein the step of attaching the first end of the first thread loop to the tubular body comprises attached the first thread to the stent.

18. The method of claim **15**, wherein the second thread includes a pull tab disposed at a first end of the second thread opposite the second thread loop and where the step of pulling the second thread comprises pulling the pull tab.

19. The method of claim **15**, wherein the step of inserting the trigger wire through the first thread loop comprises inserting the trigger wire in a longitudinal direction relative to the tubular body.

20. The method of claim **15**, wherein the self-expanding endovascular prosthesis comprises a plurality of self-expanding stents, a plurality of first threads having first thread loops, and a plurality of second threads having second thread loops,

wherein the steps of interlocking, attaching, extending, and pulling comprise performing these steps with each of the plurality of first threads and second threads corresponding to a respective one of the plurality of self expanding stents, and

wherein the step of inserting a trigger wire through the first thread loop and not through the second loop comprises inserting the trigger wire through each of the first thread loops and not through each of the second thread loops.

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